

## Characterization of the Ultra-Wide Band Channel

Marco Di Renzo<sup>1</sup>, Mauro Feliziani<sup>2</sup>, Fabio Graziosi<sup>2</sup>, Giuliano Manzi<sup>1</sup>,  
and Fortunato Santucci<sup>2</sup>

<sup>1</sup> WEST Aquila srl (Wireless Embedded Systems Technologies  
LAquila), Montelucio di Roio, 67040, LAquila, Italy  
manzi@westaquila.com, direnzo@westaquila.com, www.westaquila.com

<sup>2</sup> Center of Excellence DEWS, University of LAquila, Montelucio di  
Roio, 67040, LAquila, Italy graziosi@ing.univaq.it,  
santucci@ing.univaq.it, felizian@ing.univaq.it

## Introduction

Ultra Wide Band (UWB) is an emerging wireless technology. It is referred to as baseband, impulse or carrier-free, and it has been proposed for unlicensed operations over bandwidth spanning several GHz, provided the power spectral density of transmitted signals are adherent to some emission masks (as specified by the Federal Communication Commission in the USA) suggested by coexistence issues with other systems [1]. Due to its extreme flexibility, UWB is currently considered by the research community worldwide for many applications, ranging from short range/high rate data communications in WPAN to low-cost/low-power networking in wireless sensor networks. Unlike narrow-band channels, UWB channels exhibit two main effects: multipath propagation and pulse distortion. In particular, during propagation each waveform can be reflected by an object or can penetrate through a material, thus leading to multipath propagation. Each of these effects is frequency sensitive and therefore the waveform is filtered in some way, thus resulting in a multipath component with different pulse shape. From these considerations, it follows that UWB channels are frequency selective even if the channel consists of only a single path, thus significantly altering the shape of the transmitted pulse. The channel model described in does not explicitly account for the effect of waveform distortion and the proposers only suggest to include the additional losses due to waveform distortion in the link budget margin. In this paper we intend to investigate about the frequency selective effects of common building materials in the frequency band where UWB systems are allowed to operate 3.1-10.6 GHz [1], thus deriving an UWB channel model composed by a cascade of two linear (eventually time-variant) systems that accounts for the two aspects mentioned above (i.e. multipath propagation and pulse distortion). The motivation of this work is that the analysis of the filtering effects of the transmission through common building materials is a quite unexplored aspect in the context of Ultra Wide-Band communications [2]. In particular, in [2] the analysis was restricted to the band 2-7 GHz, the purpose of this paper is to consider the bandwidth ranging from 1 GHz to 18 GHz. The analysis has been performed both in time and frequency domain, using respectively a commercial available UWB transceiver and a Network Analyzer. The channel impulse and frequency responses have been analyzed in order to compare the obtained results and find a correspondence between them. In addition, even if many propagation measurements have been performed for indoor narrowband channels and several models have been proposed in the literature [3],[4], however, due to their restriction on measurement bandwidth,

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE <b>01 JAN 2005</b>		2. REPORT TYPE <b>N/A</b>		3. DATES COVERED <b>-</b>	
4. TITLE AND SUBTITLE <b>Characterization of the Ultra-Wide Band Channel</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>WEST Aquila srl (Wireless Embedded Systems Technologies LAquila), Montelucio di Roio, 67040, LAquila, Italy</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release, distribution unlimited</b>					
13. SUPPLEMENTARY NOTES <b>See also ADM001846, Applied Computational Electromagnetics Society 2005 Journal, Newsletter, and Conference., The original document contains color images.</b>					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT <b>UU</b>	18. NUMBER OF PAGES <b>4</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			

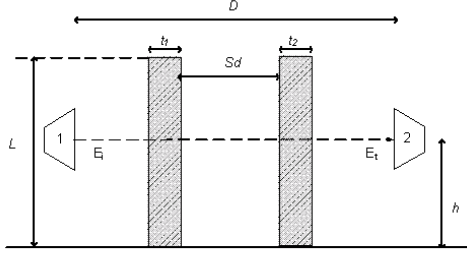


Figure 1: Measurement in presence of two walls between the transmitter and receiver antennas

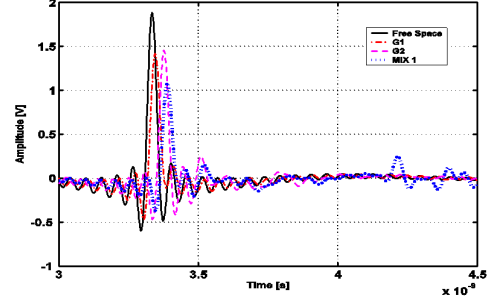


Figure 2: Impulse response of glass material in single-layer and multi-layer configurations

they are inadequate for the UWB system studies. In particular, in recent past only few investigations have been performed on the effects of common building materials at frequencies of the order of GHz, and in some circumstances only fixed frequencies have been considered [3]. The rest of the paper is organized as follows: in section 2 the measurement set-up both in frequency domain and in time domain is described; in section 3 the obtained channel model is summarized using a multiport equivalent circuit; in the and conclusions are provided.

## Measurements

### Frequency Domain Measurements

The measurement set-up used to characterize the propagation through walls is sketched in Figure 1. The measurements have been performed in frequency domain through a Vector Network Analyzer and a couple of Horn antennas, thus analyzing the behaviour of different common building materials (i.e. glass, wood) over a wide range of frequencies (1-18 GHz). To remove every multipath component, those measurements have been performed in an anechoic chamber. Two different frequency responses have been carried out from measurements: i)  $S_{21}^{fs}(w)$  measured in absence of the material under test and ii)  $S_{21}(w)$  measured with the material under test. By taking the ratio between ii) and i) it is possible to remove the antenna and free-space effects (i.e. frequency domain de-convolution), thus deriving the frequency domain response  $H(w)$ . The same experiment has been performed when more than one wall is in between the line of sight (LOS) of Tx and Rx, (see Figure 1). From the frequency domain measurements the impulse response of the channel has been obtained by taking the Inverse Fast Fourier Transform (IFFT) of the frequency response (i.e.  $h(t) = IFFT\{H(w)\}$ ). Figure 2 shows some of the obtained results in the time domain. The results shown in Figure 2 refer to three different configurations: G1, G2 and MIX1, which denote the scenarios with a glass wall of 2 mm thickness and 8 mm thickness and a combination of them (spaced by  $Sd = 1.25$  mm), interposed in between the Rx-Tx LOS. The results obtained in the MIX1 case clearly show multiple reflections between the walls: a pulse peak appears for a delay equal to the round trip time between them (i.e. 4.2 ns).

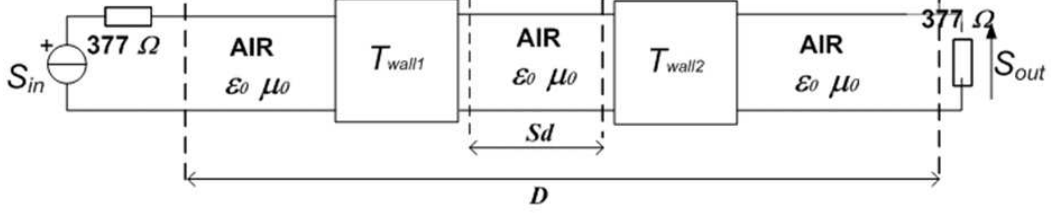


Figure 3: Equivalent circuit for calculation of the shielding effectiveness of a planar shield

## Time Domain Measurements

The same measurements described in the previous sub-section have been repeated, in the time domain, by using the P200 Evaluation Kit (EVK P200): a pair of commercial UWB pulse transceivers, developed by Time-Domain Corporation and designed to test the performance of Time Hopping (TH)- UWB systems and to accomplish the UWB channel sounding. The setup has been completed by two laptops connected to the two EVKs in order to collect and record sample waveforms. Each EVK can work both as transmitter and as receiver. When an EVK is used as transmitter it radiates a TH-UWB signal in the frequency band 3-6G Hz in the compliance with the FCC limits.

## Channel Modeling

The combination of materials has been modeled as a cascade of two-port networks connected through different transmission lines in frequency domain. The obtained equivalent circuit, which denotes the whole propagation channel (i.e. antennas, walls and air), is shown in Figure 3 where the two-port networks characterized by chain matrices  $T_{wall1}$  and  $T_{wall2}$ , the ideal voltage lumped source and the impedances denote the wall panels, the field source and the air characteristic impedance, respectively. The characteristics of each materials (i.e.  $T_{wall1}, T_{wall2}$ ) have been obtained from the frequency domain measurements. More details about the derivation of  $T_{wall1}, T_{wall2}$  will be provided in the full paper. The voltage source  $S_{in}$  is the signal generated by the Network Analyzer.  $S_{out}$  is the signal propagated through the materials and received by the antenna  $S_{21}(w)$ . The equivalent circuit depicted in Figure 3 has been simulated in the frequency domain and the obtained results agree with the ones derived from measurements. As example a comparison between a propagation of an Ultra Wide Band pulse through a glass wall with a thickness of 0.004m computed with the model and a timed domain measurements are shown in figure 4. From the figure a good agreement between computed (circled line) and measured (continuous lines) can be observed. As last example a computed propagation in the case of two glass wall with  $Sd = 0.05m$  and a thickness of 0.004m is shown in figure5.

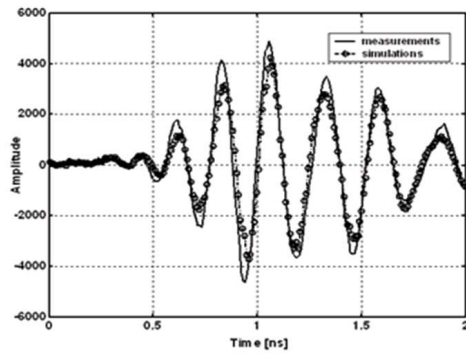


Figure 4: Measurements and simulation in case a single glass wall

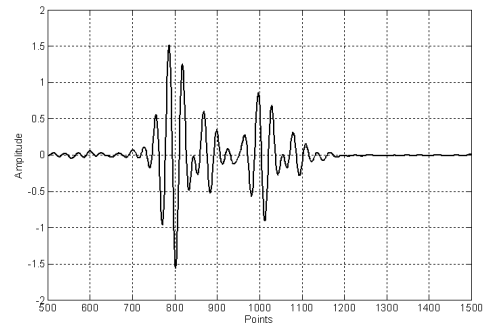


Figure 5: Simulation in case a two glass walls

## Conclusions

In this paper the propagation of Ultra Wide Band (UWB) radio communication signals through common building materials widely used in indoor environment as glass, wood and dry-wall has been investigated by measurements and simulations. A series of measurements have been performed, in anechoic chamber, in order to deduce the electromagnetic properties of UWB signals in the frequency band allowed for indoor communications. The outlined procedure leads to an equivalent electromagnetic model of the UWB propagation through materials. The obtained results are in agreement with measurements and then they can be used to simulate the propagation of UWB signal through different combinations of materials. Additional details and results about the UWB propagation through materials will be provided in the final version of the paper.

## References

- [1] FCC:  
Revision of Part 15 of the Commission's Rules Regarding Ultra Wideband Transmission Systems, First Report and Order, ET Docket 98-153, February, 2002.
- [2] R. D. Wilson, R. A. Scholtz:  
Template Estimation in Ultra-Wideband Radio, the Thirty-Seventh Asilomar Conference on Signals, Systems and Computers, 2003 Vol. 2, pp. 1244-1248 9-12, November 2003.
- [3] I. Cuias and M.G. Snchez:  
Building Material Characterization from Complex Transmissivity Measurements at 5.8 GHz, IEEE Trans. Antennas Propagat., Vol. 48, pp 1269-1271, 2000.
- [4] Safaai-Jazi, S. M. Riad, A. Muqaibel, A. Bayram:  
Through-the-Wall Propagation and Material Characterization, TECHREPORT Department of Electrical Engineering Virginia Polytechnic Institute and State University Blacksburg, 18 November 2002, Virginia.